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Target Returns for Neutral-Particle-Beam Discrimination

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TARGET RETURNS FOR NEUTRAL-PARTICLE-BEAM DISCRIMINATION

by

Gregory H. Canavan

ABSTRACT

Models of weapons and decoys adequate for deposition studies can be formulated and solved analytically. Empirical conversion efficiencies predict useful weapon signals and weapon-to-decoy signal ratios for those energies of interest. Light decoys are of concern because of the numbers possible. Discriminating them on the basis of mass appears feasible with hydrogen or deuterium beams, contrary to earlier studies of much heavier decoys.

I. INTRODUCTION

This note discusses return neutron signals expected when weapons or decoys are irradiated by 50- to 200-MeV neutral particle beams (NPBs). It derives a simple model for the areal mass densities of weapons and decoys--the main parameter that distinguishes between them. Empirical conversion efficiencies are used to estimate the ratios of weapon and decoy return signals, which indicate that weapons and light decoys should be distinguishable at NPB energies as low as 50-100 MeV.

II. SIGNAL RATIOS

Weapon-to-decoy signal ratios, which determine the rate at which objects can be discriminated, depend primarily on the weapon and decoy masses and the NPB energy, current, and discrimination sensors.

A. Deposition

Discrimination signals are proportional to the NPB's energy deposition, which depends on the irradiated object's mass. Thus, signals scale as the particle's deposition range, which is

$$L(g/cm^2) = K \cdot E^{7/4}, \qquad (1)$$

where E is the beam energy in MeV, $K = 3.3 \cdot 10^{-3} \div A_p^{3/4}$, L is the areal density, and A_p is the atomic number of the hydrogen isotope used in the beam.[1] As a point of reference, for a 100-MeV hydrogen beam, $L \approx 10\ g/cm^2$, and for a 200-MeV beam, $L \approx 35\ g/cm^2$.

B. Areal Densities

Areal densities, which are the product of the average chord length and object density, are much greater for weapons than for decoys.

1. Weapon Areal Densities

A weapon of mass M has an average areal density of

$$L_W \approx \mu r_W = (3\mu^2 M/4\pi)^{1/3}, \qquad (2)$$

where $\mu \approx 3\ g/cm^3$ is the weapon's average density and $r_W \equiv (3M/4\pi\mu)^{1/3}$ is its effective radius. L_W is about 25 cm for M = 200 kg (Appendix A). For M = 200 kg, $L_W \approx 75\ g/cm^2$, which is about twice the range of a 200-MeV proton. Thus, $L_W >> L$, so weapons are thick to particle energies of interest.

2. Decoy Areal Densities

Decoys are not generally thick. For a decoy of mass $\beta \cdot M$, which is concentrated in a thin shell, the average areal density traversed by a particle is

$$L_D \approx \beta M/\pi r_W 2, \qquad (3)$$

where L_D is the areal density of the decoy (Appendix B). Decoys cannot increase L_D by reducing r_W because they must match the weapon's r_W to be credible. Thus,

$$L_D \approx (\beta M/\pi)/(3M/4\pi\mu)^{2/3} \approx \beta M^{1/3}(4\mu)^{2/3}/\pi \approx 1.6\beta M^{1/3}. \quad (4)$$

For β = 1% and M = 200 kg, $L_D \approx 0.9$ g/cm^2, so that for E = 100 MeV protons, $L_D/L \approx 0.9$ g/cm^2 ÷ 10 g/cm^2 ≈ 0.09. Thus, light decoys would be thin to 100-MeV NPBs; they would only stop about 0.9 ÷ 35 g/cm^2 or about 30% of a 200-MeV NPB.

3. Heavy Decoys

Heavier decoys need not be thin. A 10% decoy would have an $L_D \approx 9$ g/cm^2, which is about the range of a 100-MeV proton beam to which the decoy would be thick. Heavy decoys are not, however, of primary interest. They could be addressed effectively without discrimination.

A heavy missile that carried 10 weapons could, by off loading half of them, provide about five 10% decoys for each remaining weapon, after allowing for the dispenser's mass. Such missiles cost about $200M, so the average value of any object in the 5 weapons plus 5 x 5 decoys would be about $200M divided by 30 or about $7M. Because ground-based interceptors cost about $2M on a comparable basis,[2] they could intercept the objects with a cost effective ratio of about $7M:$2M, or 3.5:1, without discrimination.

If, however, the missile dispensed fifty 1% decoys with each weapon, the value per threat object would drop to about $200M ÷ (5 + 5·50), or about $0.8M, for which $2M ground-based interceptors would be at a disadvantage. For that reason, the numerous light decoys possible in midcourse are of greatest concern. Heavy objects only need to be identified, which their mass facilitates.

4. Total Signals

For light decoys the total signal generated by a decoy of mass βM is proportional to

$$L_D \pi r_W 2 \ \alpha \ (\beta M/\pi r_W 2)\pi r_W 2 = \beta M, \quad (5)$$

i.e., the decoy's mass, which is the one parameter of a weapon that a decoy cannot afford to duplicate. The ratio of the areal densities of the decoys and weapons is

$$L_D/L_W \approx \beta M^{1/3}(4\mu)^{2/3}/\pi(\mu^2 M/4)^{1/3} = 4\beta/\pi, \tag{6}$$

independent of M. For $\beta = 1\%$, $L_D/L_W = 0.6\%$; for $\beta = 10\%$, $L_D/L_W \approx 6\%$. Either would give useful ratios of decoy-to-weapon signals for discrimination.

C. Signal Ratios

The signal from a weapon reflects the deposition of the whole NPB. Except for very high energies, where the beam begins to penetrate the weapon significantly, a weapon's signal is relatively constant. The decoy signal reflects the deposition of a fraction of about L_D/L of the beam; the rest passes through for energies and masses of interest. For $L_D/L \geq 1$, the ratio tends toward unity. An interpolation formula for the ratio of weapon-to-decoy signals that correctly describes both limits is $(L+L_D)/L_D$. For large L, it reduces to

$$L/L_D \approx 0.6 \cdot K \cdot E^{7/4}/\beta M^{1/3}. \tag{7}$$

Figure 1 shows $(L+L_D)/L_D$ as a function of E for $L_D = 0.9\ \text{g/cm}^2$ (a 1% or 2-kg decoy) and $2.7\ \text{g/cm}^2$ (a 3% or 6-kg decoy), which roughly span the values of interest. The curves scale inversely with β, so lighter decoys would give higher ratios. For 3% decoys, L/L_D is at about unity at E = 50 MeV; it increases to about 4 at 100 MeV and 14 at 200 MeV. For 1% decoys, L/L_D is about 4 at E = 50 MeV, about 12 at 100 MeV, and about 50 at 200 MeV. For light decoys, there is adequate signal ratio for all but the lowest energy hydrogen beams.

The beam energy must be chosen to keep the weapon signal much larger than the decoy's signal, i.e., $L/L_D \gg 1$. If the minimum useful signal ratio is $L/L_D = S_{WD}$, the minimum useful energy is

$$E_{min} = (1.6 \cdot S_{WD}\beta M^{1/3}/K)^{4/7}. \tag{8}$$

For $S_{WD} = 3$, $\beta = 1\%$, and M = 200 kg, $E_{min} \approx 45$ MeV. For $S_{WD} = 10$, $E_{min} \approx 90$ MeV. E_{min} scales weakly on $\beta^{4/7}$ and $M^{4/21}$. For $S_{WD} = 1$, E_{min} can be determined from Fig. 1. Thus, there are reasonable weapon-to-decoy signal levels for a range of decoy masses.

D. Conversion Efficiency

The previous section makes the tacit assumption that the conversion efficiency from NPB energy to the output signal ϵ' is about the same for weapon and decoy materials. Such an assumption is roughly the case for relevant materials, but ϵ' does vary strongly with NPB energy.

1. Hydrogen Beams

The conversion efficiency of deposited NPB energy into output signals involves a number of complex processes, but for hydrogen beams, the overall efficiency scales on beam energy as roughly $\epsilon' \propto E^3$. That scaling holds most closely for low-energy neutrons, but it also holds approximately for high-energy neutrons and gamma rays. The calculations below were made under the assumption that this scaling applies to all signals from the interaction of hydrogen beams with weapons and decoys. Specifically, it is assumed that $\epsilon' = (E/200\ \text{MeV})^3$. Thus, $\epsilon' = 1$ at $E = 200$ MeV. The conversion efficiency falls to about 1.5% at $E = 50$ Mev, which would require an approximately 100-fold longer irradiation time.

Thus, the ratio of weapon and decoy signals should be given correctly by Fig. 1, although each increases strongly with E. Figure 2 shows the conversion efficiency for 1%, 3%, 10%, and 30% decoys and the E^3 scaling of the thick target. The decoys that are greater than or equal to 10% tend to cluster, particularly at low energies where all of them are thick. The decoys that are less than or equal to 3% spread out. The ratio of the 3% and 1% conversion efficiencies at all energies is about 3:1, which is the ratio of their masses. Although suppressed at low energies, the signals, like their signal-to-noise ratios, appear to be usable, which earlier, more precise calculations obscured through their assumption of very heavy decoys.[3]

2. Deuterium Beams

Deuterium beams offer stronger deposition, less divergence, and better conversion efficiency.

a. Deposition

The previous estimates were for hydrogen beams; there are some differences for heavier isotopes. From Eq. (1), $L = K \cdot E^{7/4} \propto E^{7/4}/A_p^{3/4}$, which means that heavier isotopes have shorter deposition ranges at a given energy. That may or may not act to their advantage. For the examples above, according to Eq. (7) decreasing L would decrease the weapon-to-decoy signal ratio, which would be undesirable.

b. Divergence

Offsetting the effect of deposition is the beam divergence. For foil neutralizers the NPB full-angle divergence scales as[4,5]

$$\theta = \theta_p/\sqrt{E} = 30\ \mu\text{rad-}\sqrt{\text{MeV}}/\sqrt{(E \cdot A_p)} \propto 1/\sqrt{(E \cdot A_p)}. \qquad (9)$$

An ideal 100-MeV hydrogen beam would have a divergence of $\theta \approx 3\ \mu$rad. A deuterium beam would produce a divergence a factor of $\sqrt{2}$ less, or about 2 μrad, which would produce better collimation and deposition on distant targets.

The far-field beam diameter scales as θ^2, and the flux scales as θ^{-2}. That would increase the signal from a thick target by a factor proportional to $\theta^{-2} \propto A_p$. The signal from a thin decoy would, however, increase as $1/L\theta^2 \propto A_p^{7/4}$, so the weapon-to-decoy signal ratio would fall as $L \propto 1/A_p^{3/4}$. At a given energy, that would make hydrogen beams more effective than deuterium beams by about 70%.

c. Conversion Efficiency

A potentially more important advantage is the possibility of operating at lower beam energies. The $\epsilon' \propto E^3$ scaling of hydrogen beams comes from the high activation energies of the conversion processes. The more weakly bound neutron in deuterium could be released efficiently in collisions at lower energies. If such a condition makes it possible to operate at lower beam energies without loss of signal, deuterium could reduce the size and cost of NPB platforms.[6]

Calculation and recent experiments[7] indicate that the conversion of deuterons to neutrons in thick targets scales approximately as $\epsilon_D' \approx 2\text{-}3 \times (E/200\ \text{MeV})^2$ for heavy materials. For light materials like carbon, which is common in decoys, the conversion ratio is a factor of approximately 2 less. Whereas deuterium conversion efficiencies are comparable with those for hydrogen at high beam energies, at $E \approx 50$ MeV, the ratio $\epsilon_D'/\epsilon' \approx 3/(E/200\ \text{MeV}) \approx 12$, which would enhance signals significantly.

Deuterium's higher conversion efficiency is offset by predictions that thin-target conversion cross sections for light materials remain large (≈ 1 barn) to $E \approx 25$ MeV, and production efficiencies for light materials could be higher by about a factor of 2 relative to heavy materials at low energies. For this study, the E^2 production is used for weapons and the thin-target cross sections are used for decoys.

3. Overall Conversion Efficiency

Subsection II.B treated the areal density dependence of the conversion efficiency; Subsection II.D treated its energy dependence. Their combination gives the overall conversion efficiency. The thick target conversion efficiency is $\epsilon' \propto E^\Gamma$, where $\Gamma \approx 3$ and 2 for hydrogen and deuterium, respectively. That scaling holds essentially without modification for weapons, which are thick. For decoys, ϵ' can be corrected approximately for partial deposition by multiplying it by a factor of $L_D/(L_D+L)$, which approaches 1 for thick decoys and L_D/L for thin decoys, as discussed in Subsection II.B.2. The overall conversion efficiency is thus

$$\epsilon = \epsilon' L_D/(L_D+L). \qquad (10)$$

For $L << L_D$, $\epsilon \propto \epsilon'$, the thick target limit; for $L >> L_D$, $\epsilon \approx \epsilon' L_D/L \propto E^\Gamma L_D/E^{7/4} \approx L_D E^{\Gamma-7/4}$. Thus, $\epsilon \propto E^{5/4}$ for hydrogen, i.e., ϵ scales slightly more strongly than linearly on E. For deuterium the scaling is $\epsilon \propto E^{1/4}$, which is weak.

The transition between the two limits occurs at $L = L_D$, i.e., at $E = (L_D/K)^{4/7} \approx (1.6\beta M^{1/3}/K)^{4/7}$, which is at about 90 MeV for M = 200 kg and β = 10%, scaling weakly on $M^{4/21}$ and $\beta^{4/7}$. As a result, it is difficult to observe the mass scaling of ϵ in the region of 100 MeV for 10% decoys or 200 MeV for 40% decoys. For 1% decoys, however, the transition is at about 25 MeV, so that the scaling is essentially $\epsilon \alpha L_D/L$, and the total return varies as $E^{\Gamma}L_D r_W{}^2/L \alpha \beta M E^{\Gamma-7/4}$, which scales linearly on βM. That scaling is the basis for the inference of the object's mass.[8]

For energies such that $L_W \approx L$, the ratio of the signals from weapons and decoys is about L_D/L_W, which is about β according to Eq. (6). Generally, $L_W > L$, so the ratio of the signals is less than β by a factor of 2-3.

III. RESULTS

Figure 3 shows the hydrogen- and deuterium-beam conversion efficiencies on thick targets. At 200 MeV, deuterium-beam conversion efficiencies are a factor of 3 above hydrogen-beam conversion efficiencies; at 50 MeV, the deuterium conversion lies higher by about the factor of 12 discussed above. These conversion efficiencies are adequate at all energies for deuterium beams; they fall below 0.1 at $E \approx 100$ MeV for hydrogen.

Figure 4 shows the weapon-to-decoy signal ratio as a function of E. The top two curves are for hydrogen and deuterium for 1% decoys; the bottom two curves are for 3% decoys. The ratios are higher for lighter decoys. For 1% decoys, the ratio for hydrogen is about 4.5:1 at 50 MeV; for deuterium, it is about 3:1. For 3% decoys the ratios are both about 2:1. For 1% decoys, both exceed a weapon-to-decoy signal ratio of 10:1 by about 100 MeV. For 3% decoys, achieving that ratio requires an energy of about 170 MeV for hydrogen and about 210 MeV for deuterium.

A rough figure of merit is the product of conversion efficiency and weapon-to-decoy signal ratio. At 50 MeV for hydrogen, that product is about $0.016 \times 4.5 \approx 0.072$; for deuterium, it is $0.19 \times 3 \approx 0.57$, which is a factor of about $0.57 \div 0.072 \approx 8$ higher. The reason for preferring deuterium is that the signals predicted by the simple scaling model are larger by about a factor of 12. Getting an adequate signal is the main problem at low energies; unless that can be achieved, signal ratios are not useful. For discrimination, one must have adequate signal ratios and weapon-to-decoy signal ratios.

Figure 5 shows the hydrogen and deuterium weapon-to-decoy signal ratios as functions of the decoy areal density L_D for E = 100 and 200 MeV. For E = 100 MeV, the lower pair of curves, at $L_D \approx 10$ g/cm^2, or 10% decoys, there is little separation; both hydrogen and deuterium have values approaching unity. At lower L_D, the ratios rise rapidly. Below about 1 g/cm^2, the ratios for both hydrogen and deuterium are over 10:1, indicating that there would be an adequate basis for discrimination. Useful ratios for discrimination persist to 2-3 g/cm^2. Thus, 100-MeV beams could treat the light decoys of greatest interest.

The upper pair of curves for 200 MeV shows ratios of 3-4:1 at $L_D \approx 10$ g/cm^2, with little separation between hydrogen and deuterium. Hydrogen beams with energies of 200 MeV reach a ratio of 10:1 at $L_D \approx 4$ g/cm^2; deuterium beams reach the same ratio (10:1) at $L_D \approx 2$ g/cm^2. Beam energy is thus a useful degree of freedom, although light decoys could be addressed by lower energies.

Figure 6 shows the hydrogen- and deuterium-beam energies required to discriminate decoys of areal densities of $L_D = 0.9$ to 16 g/cm^2 (1% to 15% of the mass of a 200-kg reentry vehicle). For 1% decoys, the energies required to produce a weapon-to-decoy signal ratio of 2:1 is about 30 MeV for either hydrogen or deuterium; 4% decoys would require energies of about 50 MeV; and 8% decoys would require energies of 80-100 MeV. For any mass of interest, the corresponding energy can be read off the curves. For much of the region, the energy required to discriminate varies as $E \propto L_D^{4/7}$, the inverse of Eq. (1). Thus, the mass of those decoys discriminated can be increased with less than a proportional increase in beam energy.

IV. CONCLUSIONS

Models of weapons and decoys that are adequate for NPB deposition studies can be formulated simply and solved analytically. Decoys with masses of a few percent of those of weapons are of the greatest concern. Empirical conversion efficiencies give useful weapon signals and weapon-to-decoy signal ratios for all but the lowest energies. Deuterium beams could be required at lower energies, but discriminating the light decoys of concern on the basis of their masses appears to be possible with either hydrogen or deuterium beams for all energies of interest.

APPENDIX A

WEAPON AREAL DENSITY

A spherical, uniform mass distribution of radius r_W has a chord length

$$h = 2(r_W^2 - r^2)^{1/2} \quad \text{(A-1)}$$

at radius r from its axis and, hence, an average chord length of

$$\langle h\rangle = \Sigma_0^{r_W} dr\ 2\pi r\ 2(r_W^2 - r^2)^{1/2} \div \pi r_W^2 = 4r_W/3 \quad \text{(A-2)}$$

and an average areal density of $L_W = \mu\langle h\rangle = 2(2\mu r_W)/3$, or 2/3 of the maximum chord length.

If the density varies with radius, the average shifts, and the calculation is more complex, but a simple example illustrates the typical result. If the dense materials were concentrated within a radius $f \cdot r_W$ of the center, the average chord length would be

$$\langle h\rangle = \Sigma_0^{fr_W} dr\ 2\pi r\ 2(r_W^2 - r^2)^{1/2} \div \pi r_W^2 = 4f^{3/2} r_W/3, \quad \text{(A-3)}$$

and the average areal density would be $2(2\mu r_W f^{3/2})/3$. For f = 1 the previous result, $\langle h\rangle = \langle h\rangle_{uniform}$ is recovered. For f = 0.5, $\langle h\rangle \approx 0.35 \cdot \langle h\rangle_{uniform}$; for 0.75, $\langle h\rangle \approx 0.65 \cdot \langle h\rangle_{uniform} \approx r_W$. These estimates cannot be fundamentally improved without additional information about the weapon, which is not available. Thus, the text uses the intermediate relationship $\langle h\rangle \approx r_W$ for all weapons. Because weapons are generally thick, a more precise relationship is not needed.

APPENDIX B

DECOY AREAL DENSITY

A decoy whose mass is concentrated in a layer of thickness δ has a chord length h at radius r from its center of

$$h = 2(r_W^2-r^2)^{1/2} - 2[(r_W-\delta)^2-r^2]^{1/2}, \qquad \text{(B-1)}$$

where the first term is as in Eq. (A-1), and the second corrects for the central void. Its average chord length is thus

$$\langle h\rangle = 4\pi\{\Sigma_0^{rW}dr\ r[r_W^2-r^2]^{1/2}-\Sigma_0^{rW-\delta}dr\ r[(r_W-\delta)^2]^{1/2}\} \div \pi r_W^2$$
$$= (4r_W/3)[1-(r_W-\delta)^3/r_W^3]. \qquad \text{(B-2)}$$

For typical parameters, e.g., $\beta = 1\%$, M = 200 kg, $r_W = 25$ cm, and $\mu \approx 1\ g/cm^2$, $\delta \approx \beta M/4\pi\mu r_W^2 \approx 0.2$ cm, $\delta/r_W < 1\%$, and

$$\langle h\rangle \approx (4r_W/3)(3\delta/r_W) \approx 4\delta, \qquad \text{(B-3)}$$

so that the average areal density is

$$\mu\langle h\rangle \approx 4\mu\delta \approx \beta M/\pi r_W^2, \qquad \text{(B-4)}$$

independent of μ. The decoy could increase $\mu\langle h\rangle$ by decreasing the radius within which most of its mass was contained, but for thin decoys the total signal would still scale as $\mu\langle h\rangle r_W^2\ \alpha\ \beta M/\pi$, which only depends on the decoy's mass.

REFERENCES

1. G. H. Canavan and J. Browne, "Roles for Neutral Particle Beams in Strategic Defense," Los Alamos National Laboratory report LA-11226-MS, April 1988.

2. J. Gardner, E. Gerry, R. Jastrow, W. Nierenberg, and F.Seitz, "Report of the Technical Panel on Missile Defense in the 1990s," Washington, Marshall Institute (1987).

3. H. Sandmeier, private communication, Los Alamos National Laboratory, February 1986.

4. A. Carter, "Directed Energy Missile Defense in Space," (Washington, D.C.: U.S. Congress, Office of Technology Assessment, OTA-BP-ISC-26, April 1984).

5. N. Bloembergen and C. Patel, "Report to the American Physical Society of the Study Group on Science and Technology of Directed Energy Weapons," Reviews of Modern Physics 59(3), part II (July 1987).

6. R. Joseph, private communication, Los Alamos National Laboratory, October 1989.

7. E. Arthur, private communication, Los Alamos National Laboratory, October 26, 1989.

8. G. H. Canavan and J. Browne, "Roles for Neutral Particle Beams in Strategic Defense," op. cit., p. 61.

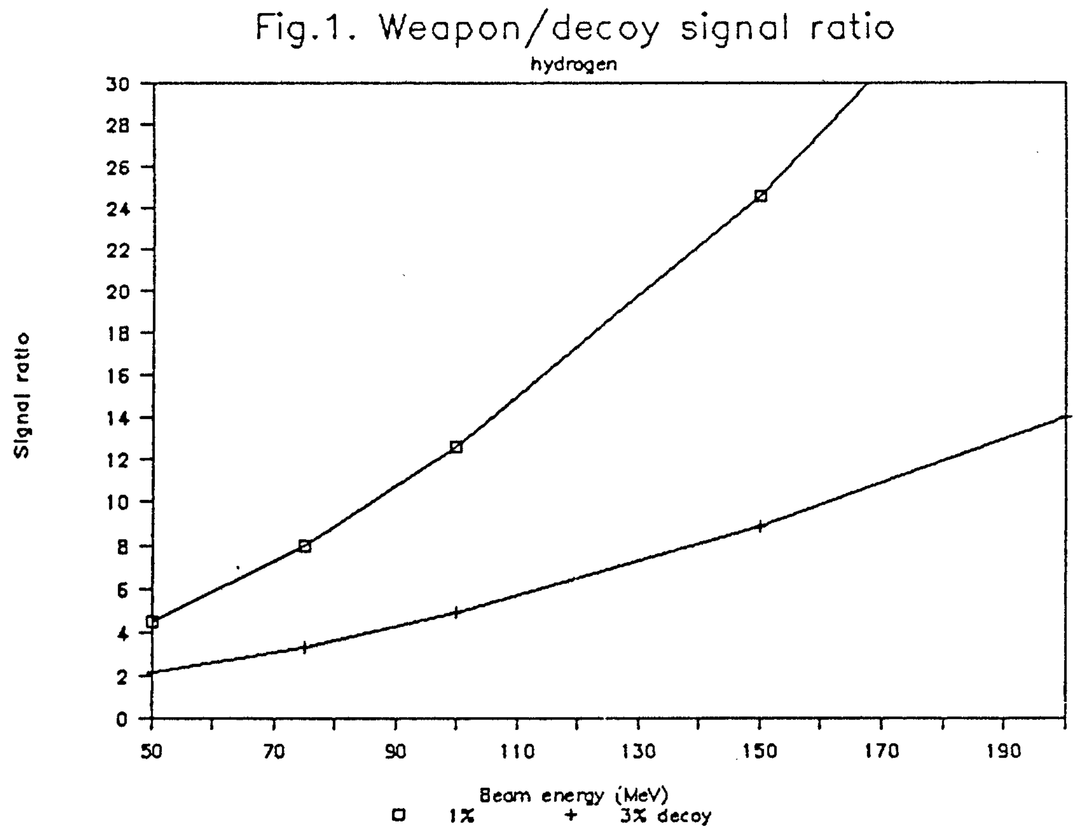


Fig.1. Weapon/decoy signal ratio
hydrogen
Signal ratio
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
50
70
90
110
130
150
170
190
Beam energy (MeV)
1%
3% decoy

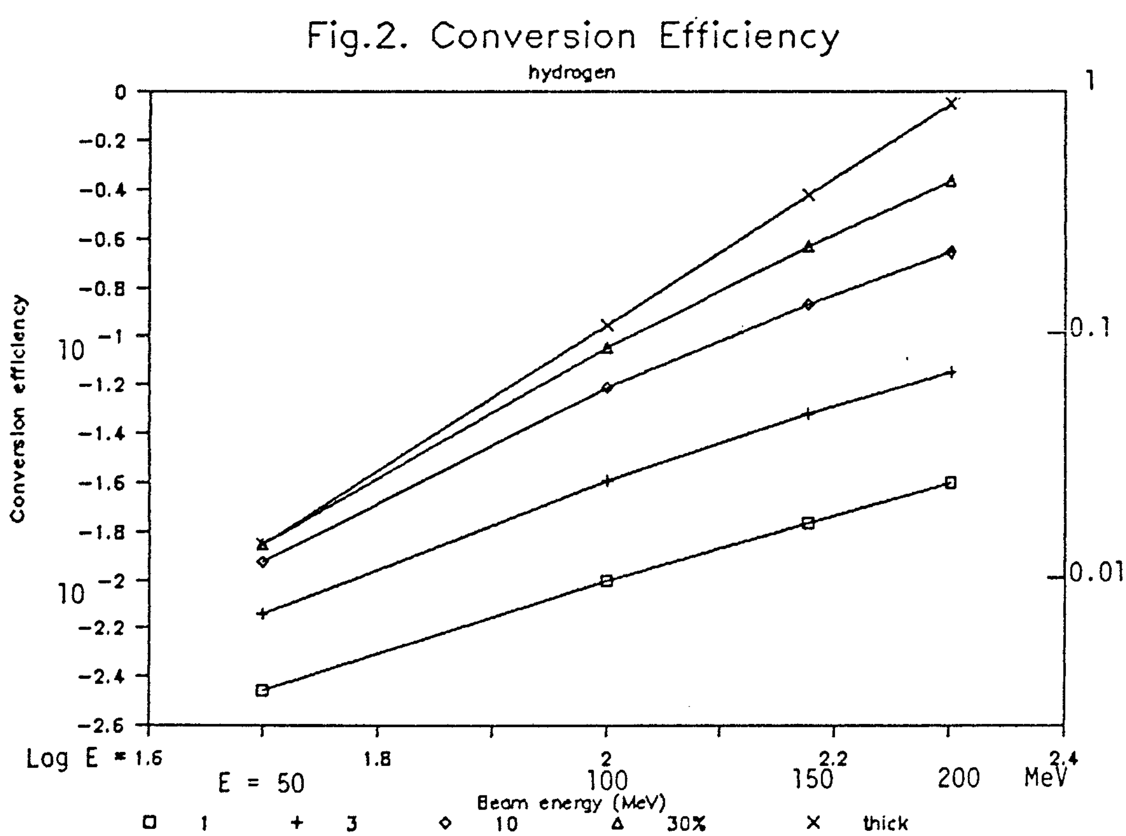


Fig.2. Conversion Efficiency
hydrogen
Conversion efficiency
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2
-2.4
-2.6
10 -1
10 -2
1
0.1
0.01
Log E = 1.6
1.8
2
2.2
2.4
E = 50
100
150
200
MeV
Beam energy (MeV)
1
3
10
30%
thick

Fig.3. Weapon conversion efficiencies

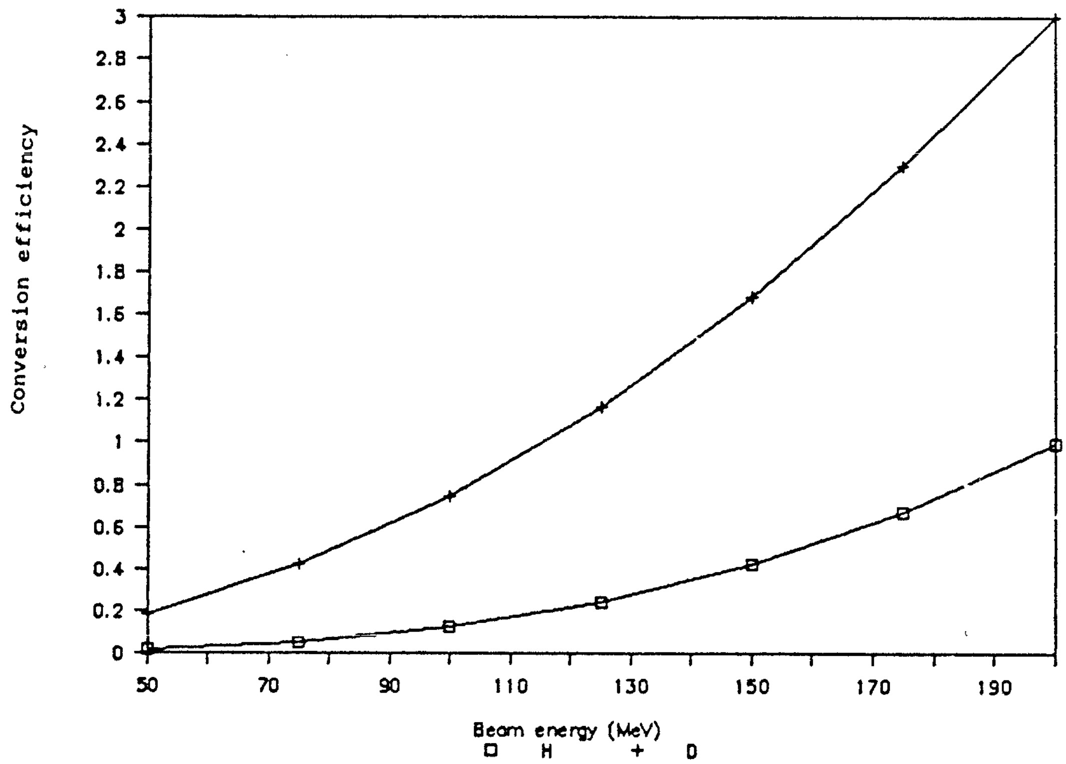


Fig.4. Weapon-to-decoy signal ratio

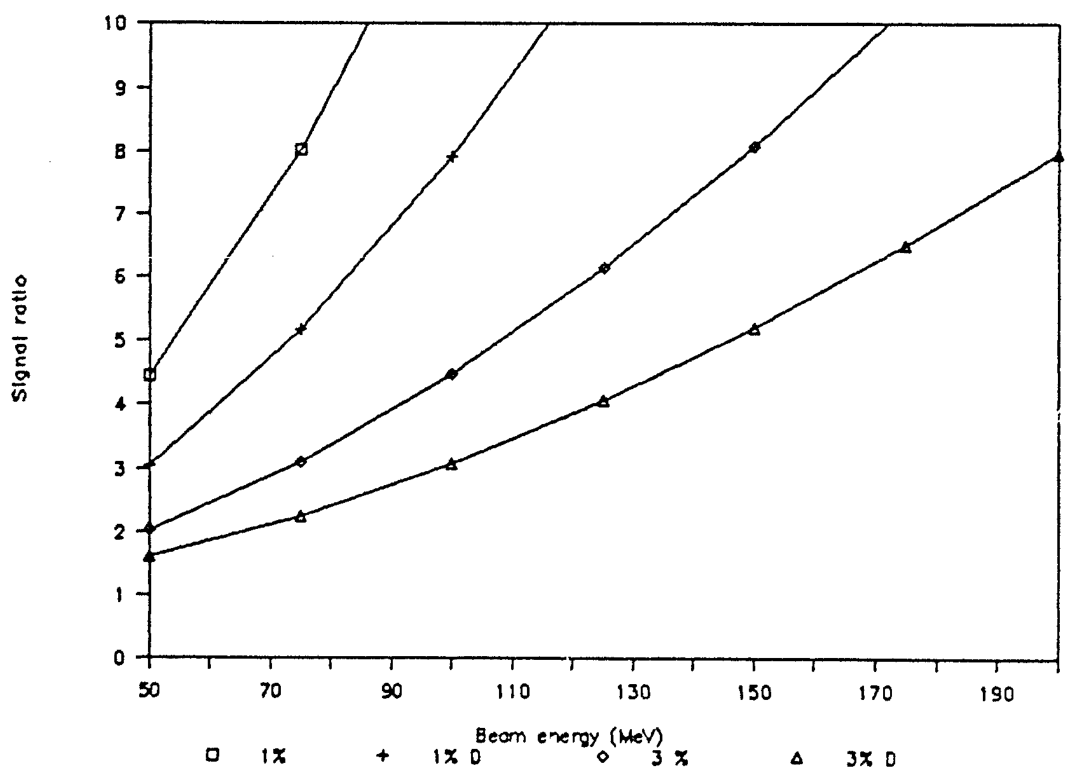


Fig.5. Weapon—to—decoy signal ratio

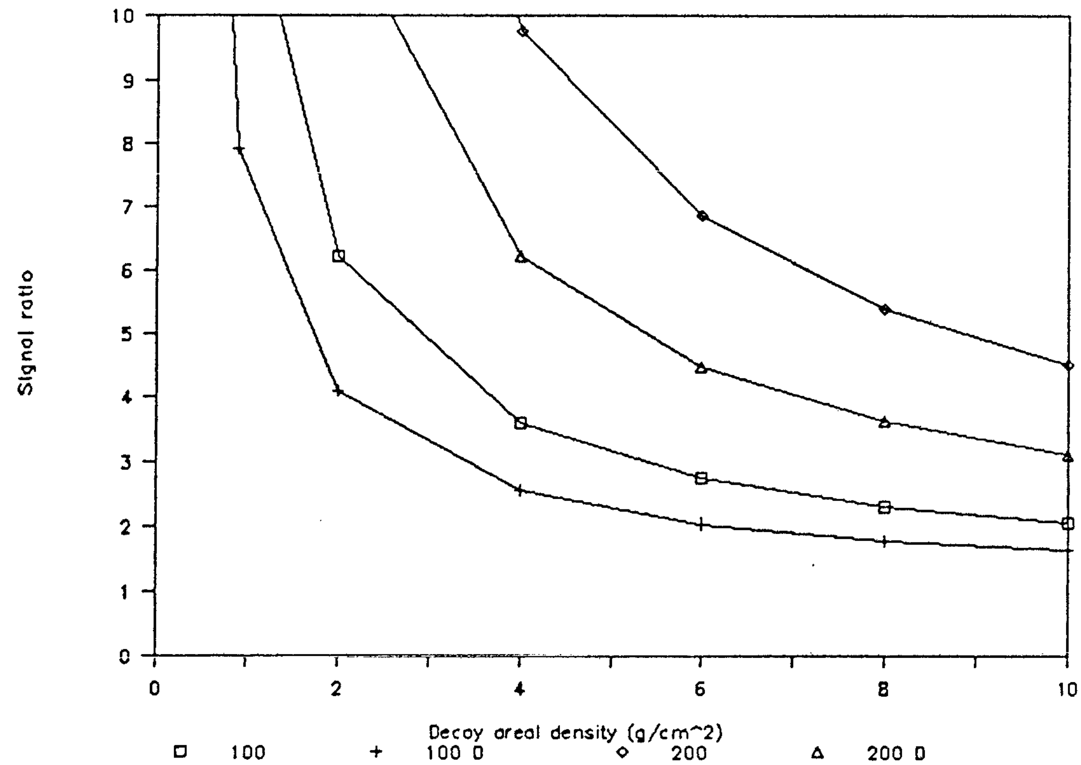
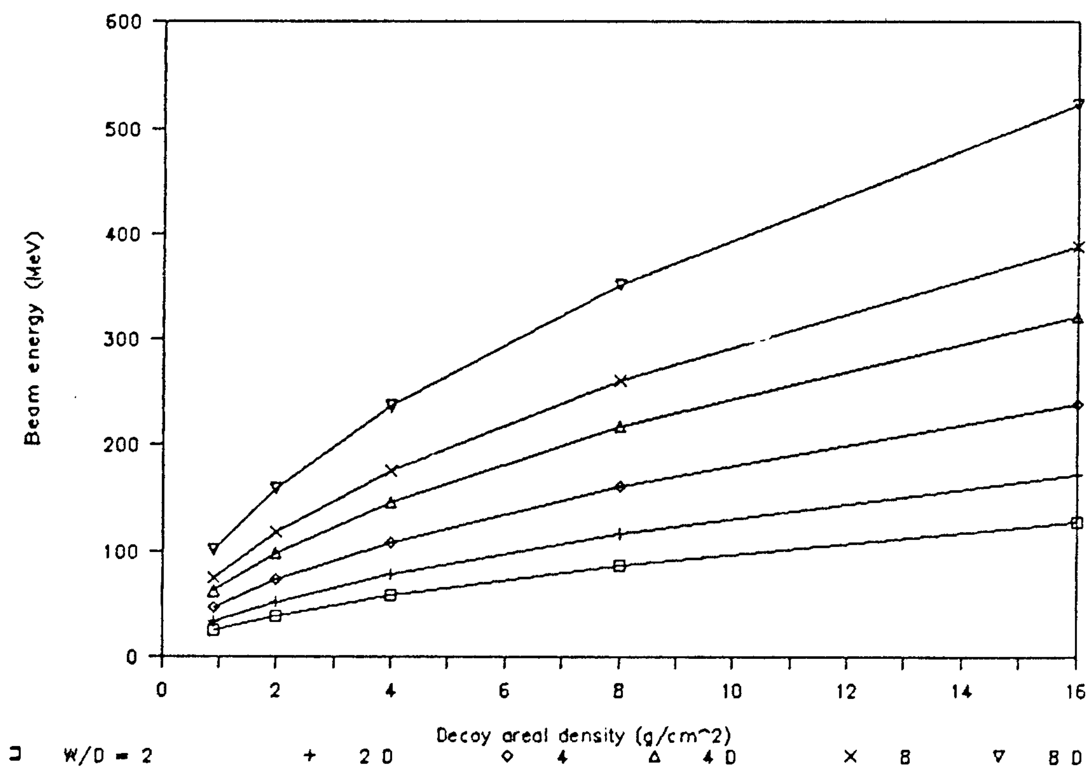


Fig.6. Energy to discriminate



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